NWT ENERGY CORPORATION (03) LTD

ASSESSMENT OF HYDROELECTRIC POTENTIAL OF THE SAHTU REGION IN NORTHWEST TERRITORIES PHASE 1

E6242

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Prepared by:

SIGMA ENGINEERING LTD
1444 Alberni Street, 4th Floor
Vancouver, BC V6G 2Z4

Phone (604) 688-8271 Fax (604) 688-1286

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DISCLAIMER

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1 INTRODUCTION

This study is prepared exclusively for NWT Energy Corporation (03) Ltd (NWT) to provide an overview assessment of the hydropower potential of the Sahtu region in Northwest Territories. The study has been performed based upon the scope of work outlined in the Sigma Engineering Ltd proposal dated July 22, 2009 and information and reports provided by NWT.

The waterpower potential of the Sahtu Region is a significant part of the total Northwest Territories' hydropower potential that has been estimated to be 11,500 MW. Development of hydroelectric resources is a priority of the Government of the Northwest Territories (GNWT), as it has been outlined in a Draft Northwest Territories Hydro Strategy that GWNT released in 2009. Hydropower is a clean, renewable and reliable source of energy, which unlike diesel generation produces very few greenhouse gases and no other air contaminants.

According to the Hydro Strategy document the development of hydroelectric power has the potential to provide a clean, long-term reliable energy source to the local energy market and possible export of the energy to other markets.

2 PREVIOUS STUDIES AND IDENTIFIED HYDROELECTRIC OPPORTUNITIES

At the first phase of the study Sigma has made a brief review of reports and information on hydroelectric projects that had been identified in the area under consideration in the last 40 years. The list of the reports we reviewed is given in Appendix 1. It should be pointed out that the identified projects are mainly medium head large-scale schemes sized primarily to provide energy to large energy consumers according to given energy demand requirements at the time. A few of the identified projects are small-scale developments sized to meet energy demands of local communities in the Sahtu Region.

To illustrate sizes and principal components of small-scale and large scale hydroelectric projects we have included a few pictures and schematics of the schemes in Appendix 2.

2.1 Great Bear River Waterpower Potential

The waterpower potential of Great Bear River, which drains Great Bear Lake, the largest lake in Canada, has been a matter of interest for a long time. The available gross head of the river from the lake outlet to its confluence with the Mackenzie River is about 110 m over a distance of about 130 km.

In 1972 G.E. Crippen performed a study 'Great Bear River Investigation' to assess the waterpower potential of the Great Bear River and to propose an optimum plan for its development. They considered and assessed two options for development:

a) Development consisting of three hydroelectric projects totaling 602 MW installed capacity: Wolverine Creek HPP, St. Charles Rapids HPP and Lower Brackett HPP

b) Development consisting of two projects totaling 568 MW of installed capacity: Head of Rapids and Upper Brackett HPP

The main features of the evaluated options are presented in the table below. In addition, Figure 1 from Crippens's report, depicting the proposed developments, is included in Appendix 3.

Option	Gross Head (m)	Installed Capacity (MW)	Total Cost ($ Mill / 1972)*
Option A			
Wolverine HPP	41.8	236.0	95.6
St Charles HPP	22.3	126.0	56.2
Lower Brackett HPP	42.1	240.0	99.0
Total	106.10	602.0	250.0
Option B			
Head of Rapids HPP	50.9	288.0	110.0
Upper Brackett HPP	49.4	280.0	112.8
Total	100.3	568.0	222.8
St. Charles**	22.3	126.0	66.5

* Cost does not include transmission line and the main step-up transformers

** Cost of the St. Charles HPP if built first

Option A provides an additional 34 MW capacity and greater flexibility with respect to development of available water power potential. In our view, the proposed hydropower development of the Great Bear River consisting of three hydroelectric projects appears to be the most economical.

The waterpower development of the Great Bear River had also been evaluated by SNC Consultants of Edmonton in 1983. (Reconnaissance Study, Hydroelectric Power for Norman Wells).

The main objective of this study was to identify hydroelectric projects within 200 km radius from Norman Wells, sized to 14 MW, which was the estimated energy demand at the time. One of the projects that SNC had identified was the Wolverine Creek HPP on the Great Bear River. The dam site of this project is the same as the Wolverine site proposed by G.E. Crippen except the project is much smaller. The main features of the project are given below:

- Installed Capacity 14 MW
- Available gross head 5m
- Firm flow 350 m³/s
- Average flow 540 m³/s
- Cost including 120 km transmission line to Norman Wells $ 42.00 Mill.

In addition to the G.E.Crippen report, we also reviewed the report prepared by Williams Project Ltd in May 2003. The main objective of the report was to assess the concept proposed by G.E Crippen and to assist NWTEC in the development of the available Great Bear River water power potential. The emphasis of the Williams report was on the assessment of the St. Charles Rapids hydropower site, which due to its size, appears to be the best suited for an initial development along the Great Bear River. Our brief assessment of this project will be provided in phase 2 of this study.

2.1.1 Brief description of the identified and assessed schemes

The 236 MW Wolverine Creek hydroelectric project is located downstream of the confluence of Wolverine Creek with Great Bear River. A general arrangement of the project proposed by G.E Crippen is provided in Appendix 3.

The scheme includes a 48 m high earthfill dam with central clay core, a powerhouse located on right bank housing 4 x 59 MW Kaplan propeller type turbines and the dam outlet works and a spillway located on the right abutment.

The general arrangement of the St. Charles Rapids HPP is also included in the Appendix 3. The project includes a 27 m high earthfill dam with central impervious core, a gated ogee type spillway and powerhouse incorporated in the dam body. The plant houses 3 units of Kaplan propeller type turbines. The layout of the project includes the spillway with two openings controlled with gates. The number of openings and associated gates depends upon the schedule of development of the projects. The selected option is based on a case when development of the project proceeds after the completion of the upstream project (the Wolverine Creek HPP). More information with respect to the concept and layout of this project will be provided in phase 2 of this study.

The 240 MW Lower Brackett hydroelectric project consists of an approximately 50 m high earthfill dam, a chute type gated spillway located on the left bank and powerplant located on the left bank. The powerhouse will house four Kaplan turbines. The general arrangement of the scheme is shown in the Appendix 3.

The total installed capacity of the three above projects that G.E. Crippen assessed and proposed is 602 MW .The second option for utilization of available hydropower potential of the Great Bear River includes the Head of Rapids and Upper Bracket hydroelectric schemes. The Head of Rapids scheme consists of a 57 m high earthfill dam, a gated concrete lined chute spillway and powerhouse housing four Kaplan turbines located on the left bank.

At the Upper Bracket site the G.E.Crippen design calls for a scheme consisting of a 54 m high earthfill dam, a gated chute spillway and powerhouse located on the left bank housing 4 Kaplan turbines.

The proposed general arrangements of the assessed projects appear to be appropriate for the given concept and relevant site conditions as known at the time. The proposed earthfill dam type with impervious central core is an appropriate choice for the given hydrological, topographical and geotechnical conditions and for projects to be built in a low temperature environment. According to the G.E Crippen report, a suitable material for construction of the dams and related core and shoulders is available in close proximity of the sites and would need to be confirmed based upon more detailed site investigations.

The Wolverine Creek HPP assessed and proposed by SNC Consultants is, as indicated before, sized at 14 MW to meet the estimated energy demand of Norman Wells at the time. The project dam site is at the same location as the one assessed by G.E. Crippen. A site plan of the proposed project is included in Appendix 3. The proposed scheme includes a 6 m high earthfilled circular cell structure with downstream sand/gravel shoulder, a gated spillway with three openings and powerhouse incorporated in the dam body. The power plant houses two units of Kaplan bulb turbines. The dam itself also includes a fish ladder.

2.2 Mackenzie River Water Power Development

A very preliminary study of 4 hydropower projects on the Mackenzie River was done by Amec E&C Services Ltd of St. Johns in 2001.

The assessed projects are large-scale run of river schemes with installed capacity ranging from 1,420 to 3,490 MW. It should be emphasized that this study, unlike the studies done by SNC and G.E Crippen, which were based on limited site field investigations including some exploratory drilling, is actually a very preliminary study and provides only 'order of magnitude' estimates of the schemes.

The main features of the three listed schemes as located in the Sahtu region are provided in the table below:

Scheme	Mean Annual Flow (m^3/s)	Usable Flow (m^3/s)	Gross Head (m)	Installed Capacity (MW)	Cost ($ Mill/01)
Johnson River G S	7,395	5,768	29	2,220	4,005.1
Lower Ramparts	8,866	6,915	38	3,490	5,906.0
Norman Wells	8,433	6.578	38	3,320	5,673.4

Figure 1 of the report depicting the assessed schemes is provided in Appendix 5.

2.3 Waterpower Potential of Tributaries to the Mackenzie River

In 1983 SNC Consultants had assessed available water power potential in an area within a 200 km radius from Norman Wells. The objective of the study was to identify and assess hydroelectric projects sized to 14 MW capacity, which was the estimated energy demand at the time.

In addition to the Great Bear River hydropower potential, the following tributaries of the Mackenzie River were screened and evaluated: Redstone River, Keele River, Mountain River and Carcajou River. Figure 3.3 of the report indicating the sites under consideration is enclosed in Appendix 4. The main findings of the study and project ranking are given in the table below

The Wolverine Creek hydroelectric project was found to be the most attractive financially.

Parameter/ Project	Wolverine HPP	Keele River HPP	Mountain River HPP	Carcajou River HPP	Redstone River HPP
Installed Capacity (MW)	14	14	14	14	14
Firm flow (m^3/s)	350	36	26	29	31
Average flow (m^3/s)	540	166	155	72	126
Reservoir length (km)	5	19	16	23	22
Dam Height(m)	5	46	62	56	52
Dam Type	Earthfilled circular cell structure	Earthfill dam	Earthfill dam	Earthfill dam	Earthfill dam
Transmission Line (km)	120	120	110	40	190
Estimated Cost ($Mill/'83) *	42	93	79	116	70
Project Ranking	1	4	3	5	2

* Costs do not include indirect costs such as contingencies, mobilization, demobilization, engineering and owner's costs.

In our view, the selected hydro sites sized according the specified power demand (14 MW installed capacity with capacity factor 0.9) meet the given concept of the project.

2.4 Other large-scale hydroelectric projects previously identified in the Sahtu Region

In 1979 the UMA Group undertook a study to assess the hydropower potential of five river basins in the Northwest Territories. The study area includes the Burnside, Hood, Hayes, Back and Camsell River. The Camsell River is the only one within the area of the Sahtu Region.

Three hydroelectric projects on the Camsell River have been identified and appraised. Their main features and cost estimates are presented in the table below:

Parameter / Project	Camsell River, Site 6- With Diversion	Camsell River Site 6- Without Diversion	Camsell River Site 7
Average Head (m)	22.0	22.0	15.0
Installed Capacity(MW)	34.0	25.0	16.8
Firm Power Capacity (MW)	20.3	16.8	9.1
Capacity factor	0.6	0.6	0.54
Firm Energy produced (GWh)	177.8	147.0	80.0
Diversion-Emile River Diversion($Mill/'79)	170.5	n/a	n/a
Diversion-Marian River Diversion ($Mill/'79)	13.6	n/a	n/a
Estimated Cost ($Mill/ '79)	205.9	172.6	190.5

Site 6 on Camsell River has been assessed with and without the Emile and Marian Rivers diversions. The diversions are proposed to divert water into the Camsell basin resulting in increasing the energy production of the scheme.

The project arrangement of site 6 is provided in Appendix 6. The scheme includes an earth embankment type main dam, a gated spillway located in a saddle upstream of the main dam, a short tunnel waterway and powerhouse located downstream of the structure. The power plant houses 4 Kaplan type turbines.

2.5 Identified Small Scale Hydroelectric Projects

Sigma had the opportunity to review three reports dealing with potential small-scale hydropower projects in the Sahtu Region. The first study we reviewed is 'An investigation of possible small hydro generating sites in the Northwest Territories' prepared by Ferguson, Naylor, Simek, Clark Ltd in 1983. It was found that the assessed schemes including Kakisa HPP are located outside the Sahtu region. The other two studies are discussed below.

2.5.1 Small Hydropower Potential on Great Bear River

2.5.1.1 Valard/Tollhouse Report 2007

A 2007 report prepared by Valard Construction and Tollhouse Energy Corporation identified four possible run-of-river hydroelectric sites on the Great Bear River. Two sites (Wolverine Creek and St. Charles Rapids) were immediately excluded from further study due to evidence of violent ice build-up that scours the banks of the river. The two remaining sites were examined in more detail and are summarized below.

Site 1 is located approximately 3.2 km downstream of the mouth of Great Bear River where the river makes a sharp bend to the south. The evaluated scheme involves constructing an intake on the north bank of Great Bear River at an elevation of approximately 159.1 m and installing a 490 m long buried penstock across a peninsula to a powerhouse to be constructed at an elevation of approximately 157.0 m. This project was initially sized specifically to provide the nearby community of Deline with power at an estimated load of 600 kW. To accomplish this, the project would require twin penstocks of 3.35 m (132") diameter polyethylene pipe and a siphon at the peak of the hill. This project would have 2.1 m of gross head and a total design flow of 36.8 m^3/s (18.4 m^3/s per penstock). The specified flows are unusually low for pipes of this size, but are justified in that the lower flows provide lower head losses. With only 2.1 m of gross head for this project, minimizing losses is critical. Assuming an 88% turbine-generator efficiency and estimated head losses of 0.3 m the scheme, as described, would provide 580 kW installed capacity.

The Valard/Tollhouse report presents a preliminary cost estimate of $21.9 million. Using US Bureau of Reclamation construction price indices this estimate was updated to give $22.4 million in 2009. The capital cost of these projects is only one element of the community energy cost. The long term energy cost of any scheme needs to be compared with the long term cost of diesel generation in order to draw a conclusion on the economic value.

Site 2 is located approximately 11.2 km downstream of the mouth of Great Bear River. The evaluated scheme consists of an intake on the south bank of the river at an elevation of approximately 153.0 m, a 4 km long buried penstock to a powerhouse to be constructed at an elevation of approximately 147.0 m. The installed capacity of the scheme is sized to meet the energy demand of the Deline community.

The scheme would require one penstock of 3.35 m (132") diameter. This project would have 6.0 m of gross head and a design flow of 13.0 m3/s. Again, the lower than usual flows for this pipe size are designed to minimize the head loss, which is critical for a project such as this with very low head. Assuming an 88% turbine-generator efficiency and an estimated head loss of 1.4 m the scheme as described would provide 550 kW installed capacity.

The Valard/Tollhouse preliminary capital cost estimate for Site 2 is $37 million.

2.5.1.2 f.s. Matrix Incorporated Report 2002 – Outlet of Great Bear Lake

A 2002 report by f.s. Matrix Incorporated (FSM) identified a run-of-river hydroelectric site near the mouth of Great Bear River. This scheme has been sized to provide power to the nearby community of Deline.

The scheme involves constructing a 3 km long channel to divert a small portion of the flow of the Great Bear River into a short penstock, through a powerhouse and immediately back into the Great Bear River. The design flow of the scheme is approximately 22.3 m^3/s and the gross head is 4 m. Assuming an overall plant efficiency of 80%, this project would provide 700 kW installed capacity.

Based on available mapping and hydrological data from previous reports on the Great Bear River this scheme seems feasible. However, largely due to its long diversion channel the project would likely be much too expensive to be financially attractive. In 2002, FSM estimated the project cost to be $24 million, slightly more than the Valard/Tollhouse site 1.

3 SCREENING OF NEW HYDROPOWER OPPORTUNITIES IN THE SAHTU REGION

After the completion of the preliminary assessment of previously identified hydroelectric opportunities, Sigma has conducted a search for new potential hydroelectric sites focusing mainly on the areas that have not been considered and assessed in the previous studies. Both small and large scale storage hydroelectric projects have been considered.

The search was conducted using 1:50,000 topographical mapping and hydrological information from relevant Water Survey of Canada (WSC) data gauges. The main focus of the search was the area of the Mackenzie Mountains near the Yukon border, and tributaries to Redstone River, Keele River, Carcajou River and Mountain River.

Hydrological conditions of the area under consideration with the unit run off ranging from 0.0036 to 0.012 $m^3/s/km^2$ are not favorable for hydropower developments.

Although most of the watercourses with drainage basins large enough to be attractive for small scale hydroelectric developments are located in an area composed of quite steep mountainous terrain, they flow along mildly sloping plateaus making traditional small scale run of river schemes infeasible.

The sections of creeks and rivers with steeper slopes are mainly narrow and constrained in canyons with deep side slopes limiting the amount of possible storage that might be formed by damming. Such a topographical setting requires construction of large dams and makes storage schemes inefficient and expensive in general.

The noted topographical and hydrological conditions of the study area, and the likely consumers of energy such as mines (requiring power plants with high installed capacity and capacity factor), led us to briefly assess the feasibility of a Storage Diversion project. A Storage Diversion project includes a relatively short penstock that makes up most of the head of the project and a dam creating storage and additional head.

We have briefly assessed a few potential sites; however have not identified any hydroelectric sites to be recommended for further studies and analysis.

In addition, Sigma has examined areas immediately around the communities of Deline, Tulita, Norman Wells and Fort Good Hope, with the objective of finding small hydroelectric sites to serve these communities directly. The topography of most of the assessed areas around the noted communities is quite mild and flat making it unattractive for small scale, run-of-river hydroelectric developments.

4 SITE ASSESSSMENT

The assessment of the identified hydroelectric projects in the Sahtu region includes the evaluation of hydrological input, project layout, installed capacity, annual generation and capital cost of the schemes. In addition, Sigma has briefly appraised relevant environmental aspects and impacts of the projects as well as issues of land use planning in the area under consideration.

4.1 Hydrology

The hydrological estimates provided in this study are meant to provide an indication of the available flows at each site and to assist the sizing of the potential hydroelectric projects. This report is not intended to be a study of the hydrology in the Sahtu region. The complexity of the different hydrologic regimes in the region (as discussed in a 2004 workshop in Yellowknife, 'Prediction in Ungauged Basins: Approaches for Canada's Cold Regions') makes extrapolation of streamflow estimates extremely difficult, especially given the limited number of gauges in the area.

A list of the available Water Survey of Canada (WSC) streamflow gauges in the Sahtu area is shown on Table A. The majority of the gauges record natural flows. Gauges on the Mackenzie River, however, are mostly regulated. This assignment utilized preferably active gauges with adequate length of record, and relatively close to the project site considered.

At the time of most of the previous studies, many of the gauges used in this report were either not installed or had few years of data. As a result, available data from more distant gauges were used in combination with regional hydrological methods to approximate the available flow and design flood at a particular project site.

All of the rivers with potential hydroelectric projects that are identified in this study have WSC gauges on them with at least 4 complete years of daily flow data. This fact provides increased confidence in the estimates of annual and monthly flows available at each site.

The available peak instantaneous and daily flow data from these gauges allow us to determine peak floods for various return periods at each site. The flood estimates should be useful in future studies that will determine the Probable Maximum Flood at each site, which impacts project design.

4.1.1 Great Bear River Hydroelectric Sites

The nearest WSC gauge to the project site(s) is 10JC003-Great Bear River at outlet of Great Bear Lake, located about 50-95 km east from the various project sites on the Great Bear River. The gauge is currently active and has 25 complete years of daily flow data from 1961 to 2008

The drainage area of the gauge is 146,400 km^2 and its Mean Annual Flow (MAF) is 537.7 m^3/s. The Unit Mean Annual Flow is 0.0037 $m^3/s/km^2$. The estimated monthly and annual flows at the WSC gauge are shown in the table below:

	Flows (m^3/s)
Jan	518.5
Feb	508.7
Mar	501.6
Apr	496.1
May	507.3
Jun	552.3
Jul	575.2
Aug	583.1
Sep	580.3
Oct	563.7
Nov	536.0
Dec	526.8
Annual	537.7

A frequency analysis of the peak instantaneous flows at WSC gauge 10JC003 is shown below:

Peak Flows (m^3/s)

Return Period	WSC – Instantaneous*	WSC - daily*
200 year	771	874
1,000 year	809	963
10,000 year	857	1100

* There are 46 peak daily flow data and only 24 peak instantaneous flow data.

The hydrology for the Great Bear River Waterpower Development is discussed and briefly presented in the 'Great Bear River Investigation' 1972 report by G. E. Crippen and Associates. The Mean Annual Flow at the WSC 10JC003 gauge was estimated at 518.2 m^3/s (18,300cfs).

The 1972 report also states that the spillway for the Wolverine River project is designed for a flood of 708 m^3/s (25,000 cfs). Assuming that the available storage at Great Bear Lake is used to control the outflow from the lake during the Probable Maximum Flood (PMF), the spillways at the various proposed sites located further downstream should be designed for the PMF of the contributing areas.

4.1.2 Mackenzie River Norman Wells HPP

The nearest WSC gauge to the project site is 10KA001-Mackenzie River at Norman Wells, located about 50 km northwest from the project site. The gauge is regulated and has 35 complete years of daily flow data from 1943 to 2008 (currently active). The drainage area of the gauge is 1,594,500 km^2 and its Mean Annual Flow (MAF) is estimated at 8,530 m^3/s.

The Unit Mean Annual Flow is 0.0054 $m^3/s/km^2$. Note that the fact that the flows at the gauge are regulated should not affect the estimate of the mean annual flow.

The mean annual flow at the Norman Wells project site (1,498,000 km^2) is estimated at 8,014 m^3/s based on the drainage area ratio.

A frequency analysis of the peak instantaneous flows at WSC gauge 10KA001 is shown below:

Peak Flows (m³/s)

Return Period	WSC – Instantaneous*	WSC - daily*	Site - Instantaneous	Site - Daily
10,000 year	47,900	35,700	45,000	33,540

* There are 47 peak daily flow data and only 15 peak instantaneous flow data.

The hydrology for the Norman Wells project is briefly discussed in the 'Report on Preliminary Layout and Cost Study – MacKenzie River Hydro' prepared by AMEC E&C Services Ltd in 2001.

The Mean Annual Flow at the Norman Wells site was estimated at 8,433 m^3/s (drainage area of 1,498,000 km^2). Using the latest data for 10KA001, the MAF at the site would be estimated at 8,014 m^3/s.

The 2001 report also states that the project spillway is designed for a PMF of 65,300 m^3/s. An estimate of the PMF was outside the scope of this study.

4.1.3 Tributaries to the Mackenzie River

4.1.3.1 Carcajou River HPP

The nearest WSC gauge to the project site is 10KB001-Carcajou River below Imperial River, located about 8 km northwest from the project site. The gauge is currently active, and has 20 complete years of daily flow data from 1976 to 2008 .Its drainage area is 7,400 km^2 and its Mean Annual Flow (MAF) is 70.6 m^3/s. The Unit Mean Annual Flow is 0.0095 $m^3/s/km^2$.

The Mean Annual Flow at the project site, based on a drainage area of 6,860 km^2, is estimated at 65.5m^3/s. The estimated monthly and annual flows at the site are shown in the table below:

	Flows (m³/s)
Jan	10.2
Feb	8.6
Mar	7.7
Apr	10.9
May	153.4
Jun	180.4
Jul	127.2
Aug	126.0
Sep	84.0
Oct	39.1
Nov	20.0
Dec	13.6
Annual	65.5

A frequency analysis of the peak instantaneous flows at WSC gauge 10KB001 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m^3/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	4,110	3,160	3,810	2,930
10,000 year	7,910	6,470	7,335	6,000

The hydrology input for the Carcajou River hydropower project is discussed in the 'Reconnaissance Study Hydroelectric Power for Norman Wells' 1983 report by SNC Consultants.

The Mean Annual Flow at the site was estimated at the time from the nearby WSC gauge 10KB001-Carcajou River below Imperial River. The stated mean annual flow of 72.1 m^3/s is not supported by the data available at the time. The MAF from 1978-1982 at the WSC gauge is 71.1 m^3/s which would correspond to a MAF of 65.9m^3/s at the project site.

The 1983 SNC report also states an average annual flood peak of 570 m^3/s and a spillway design flood of 2,150 m^3/s at the site. Based on page 3-6 of the SNC report, it seems that the spillway design flood is set equal to the 10,000-year peak daily flood.

Based on 21 data points from 1978 to 2007, the peak daily flow at the WSC gauge ranges from 200 m^3/s to 1,930 m^3/s with an average value of 821 m^3/s; while the peak instantaneous flow ranges from 357 m^3/s to 2,520 m^3/s with an average value of 1,082 m^3/s.

It appears that the spillway design flood needs to be revised upwards. Even if the same methodology used by SNC was applied to the updated data, a spillway design flood of about 6,000 m^3/s would be estimated. Current design practices for large dams use design floods equal to the Probable Maximum Flood (PMF). The estimate of the PMF was outside the scope of this study.

4.1.3.2 Mountain River HPP

The nearest WSC gauge to the project site is 10KC001-Mountain River below Cambian Creek, sited about 35 km southeast from the project site. The gauge has 17 complete years of daily flow data from 1975 to 1994. Its drainage area is 11,060 km^2 and its Mean Annual Flow (MAF) is 123.1 m^3/s. The Unit Mean Annual Flow is 0.0111 $m^3/s/km^2$.

The Mean Annual Flow at the project site, based on a drainage area of 14,200 km^2, is 158.0m^3/s. The estimated monthly and annual flows at the site are shown in the table below:

	Flows (m^3/s)
Jan	21.6
Feb	17.9
Mar	16.0
Apr	18.3
May	223.0
Jun	529.3
Jul	392.0
Aug	327.9
Sep	189.1
Oct	84.2
Nov	39.6
Dec	28.5
Annual	158.0

A frequency analysis of the peak instantaneous flows at WSC gauge 10KC001 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m^3/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	3,250	2,260	4,175	3,420
10,000 year	6,660	4,190	8,550	5,380

The hydrology for the Mountain River project is discussed and presented in the 'Reconnaissance Study Hydroelectric Power for Norman Wells' 1983 report by SNC Consultants. The Mean Annual Flow at the site is stated as 155.0 m^3/s, which is close to the present estimate of 158 m^3/s.

The 1983 SNC report states an average annual flood peak of 1,090 m^3/s, and a spillway design flood of 4,800 m^3/s , which is approximately the 10,000-year peak daily flood estimated at the time.

Based on 14 data points from 1978 to 1994, the peak daily flow at the WSC gauge ranges from 650 m^3/s to 1,680 m^3/s with an average value of 1,000 m^3/s; while the peak instantaneous flow ranges from 827 m^3/s to 2,220 m^3/s with an average value of 1,222 m^3/s.

The spillway design flood needs to be revised upwards, since $Q_{10,000}$ daily is estimated at 5,380 m^3/s .As indicated before, current design practices for large dams use spillway design floods equal to the Probable Maximum Flood (PMF). The estimate of the PMF was outside the scope of this study.

4.1.3.3 Keele River HPP

The nearest WSC gauge to the project site is 10HA004-Keele River above Twitya River, located about 58 km west from the project site. The gauge is currently active, and has 4 complete years of daily flow data from 1995 to 2008. The drainage area of the gauge is 11,200 km^2 and its Mean Annual Flow (MAF) is 134.8 m^3/s. The Unit Mean Annual Flow is 0.0120 $m^3/s/km^2$.

The Mean Annual Flow at the project site, based on a drainage area of 18,500 km^2, is estimated at 222.7m^3/s. The estimated monthly and annual flows at the site are shown in the table below:

	Flows (m^3/s)
Jan	40.9
Feb	35.5
Mar	31.6
Apr	36.2
May	360.3
Jun	713.2
Jul	435.4
Aug	378.6
Sep	341.4
Oct	163.8
Nov	72.1
Dec	53.7
Annual	222.7

A frequency analysis of the peak instantaneous flows at WSC gauge 10HA004 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m^3/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	1,380	1,320	2,280	2,180
10,000 year	1,500	1,450	2,480	2,400

The SNC report estimated the Mean Annual Flow at the site at 166 m^3/s, which is 25.4 % lower than the present estimate.

The SNC reports an average annual flood peak of 1385 m^3/s and a spillway design flood of 6,100 m^3/s at the site. Based on 9 data points from 1995 to 2007, the peak daily flow at the WSC gauge ranges from 576 m^3/s to 1,080 m^3/s with an average value of 865 m^3/s; while the peak instantaneous flow ranges from 620 m^3/s to 1,170 m^3/s with an average value of 942 m^3/s.

Current design practices use design floods equal to the Probable Maximum Flood (PMF). As stated above, the Q200 inst at the site is 2,280 m^3/s whereas the Q10,000 daily is 2,400 m^3/s. An estimate of the PMF is outside the scope of this study.

4.1.3.4 Redstone River HPP

The nearest WSC gauge to the project site is 10HB005-Redstone River, located 63km above the mouth and about 12 km northeast from the project site.

The gauge is currently active and has 15 complete years of daily flow data from 1974 to 2008. The drainage area of the gauge is 15,400 km^2 and its Mean Annual Flow (MAF) is 175.2 m^3/s. The Unit Mean Annual Flow is 0.0114 $m^3/s/km^2$.

The Mean Annual Flow at the project site, based on a drainage area of 14,000 km^2, is estimated at 158.3m^3/s. The estimated monthly and annual flows at the site are shown in the table below:

	Flows (m^3/s)
Jan	22.7
Feb	19.2
Mar	17.2
Apr	28.0
May	228.3
Jun	444.1
Jul	418.0
Aug	330.9
Sep	215.8
Oct	99.7
Nov	46.2
Dec	30.8
Annual	158.3

A frequency analysis of the peak instantaneous flows at WSC gauge 10HB005 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m^3/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	6,090	5,710	5,540	5,190
10,000 year	9,410	9,410	8550	8,560

The hydrology for the Redstone River project is discussed in the 'Reconnaissance Study Hydroelectric Power for Norman Wells' 1983 report by SNC Consultants. The Mean Annual Flow at the site is estimated from the nearby WSC gauge 10HB005. The mean annual flow of 126 m^3/s that is stated is not supported by the data available at the time. The MAF from 1974-1982 (using only years with complete data) at the WSC gauge is 155.5 m^3/s which would correspond to a MAF of 141.3m^3/s at the project site.

The 1983 SNC report also states an average annual flood peak of 1080 m^3/s and a spillway design flood of 4,750 m^3/s at the site, which appears to be 10,000-year peak daily flood (as estimated at the time of the 1983 report).

Based on 16 data points from 1980 to 2007, the peak daily flow at the WSC gauge ranges from 44 m^3/s to 3,750 m^3/s with an average value of 1,540 m^3/s; while the peak instantaneous flow ranges from 573 m^3/s to 4,110 m^3/s with an average value of 1,912 m^3/s.

It appears that the spillway design flood needs to be revised upwards. Even if the same methodology used by SNC was applied to the updated data, a spillway design flood of 8,550 m^3/s would be estimated for the 10,000 year flood. As indicated previously current practice would be to design the spillway to safely pass the PMF

4.1.3.5 Other Large Scale Hydroelectric Projects in the Sahtu Region

The nearest WSC gauge to the Camsell project site is 10JA002-Camsell River gauge. It is located at the outlet of Clut Lake, about 4 km east from the project site. The gauge is currently active and has 44 complete years of daily flow data from 1933 to 2008. Drainage area of the gauge is 32,100 km² and its Mean Annual Flow (MAF) is 102.4 m³/s. The Unit Mean Annual Flow is 0.0032 m³/s/km².

The Mean Annual Flow at the project site, based on a drainage area of 32,100 km² (see discussion on previous reports below), is 98.9 m³/s. The estimated monthly and annual flows at the site are shown in the table below:

	Flows (m³/s)
Jan	91.7
Feb	84.0
Mar	76.8
Apr	70.5
May	75.5
Jun	106.8
Jul	123.1
Aug	121.8
Sep	117.0
Oct	111.4
Nov	106.7
Dec	101.5
Annual	98.9

A frequency analysis of the peak instantaneous flows at WSC gauge 10JA002 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m³/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	260	267*	260	267
1,000 year	282	304*	282	304

* Note that the daily frequency analysis is based on 44 data points whereas the peak instantaneous frequency analysis is based on 29 available data points.

The hydrology assessment for the Camsell River project is discussed in the 'Power Site Survey Northwest Territories' 1979 report by UMA. The Mean Annual Flow at the site is estimated from the nearby WSC gauge 10JA002.

In the 1979 report the drainage area at the WSC gauge is stated as 31,000 km² and is the same as the drainage area of the project. The drainage area of the WSC gauge is now shown by WSC as 32,100 km². The MAF of 91.21 m³/s, stated at the WSC gauge is similar to flow that would be estimated using the data available at the time. The MAF from 1933-1978 (using only years with complete data) at the WSC gauge is 88.23 m³/s which would correspond to a MAF of 85.2 m³/s at the project site.

The UMA reports a spillway design flood of 7,925 m³/s at the site. Based on figure 4-6 of the UMA report, it seems that the spillway design flood is set equal to the 1,000-year peak daily flood (as estimated at the time of the 1979 report).

Based on 44 data points from 1964 to 2008, the peak daily flow at the WSC gauge ranges from 72 m³/s to 228 m³/s with an average value of 139 m³/s; while the peak instantaneous flow (29 data points) ranges from 501 m³/s to 708 m³/s with an average value of 148 m³/s.

Current design practices for large dams use design floods equal to the Probable Maximum Flood (PMF). An estimate of the PMF is outside the scope of this study.

4.1.3.6 Emile River Diversion

The nearest WSC gauges to the project site are:

10JA002 -Camsell River at outlet of Clut Lake - about 140 km northwest from the project site. The gauge has 44 complete years of daily flow data from 1933 to 2008 (currently active). Its drainage area is 32,100 km² and its Mean Annual Flow (MAF) is 102.4 m³/s. The Unit Mean Annual Flow is 0.0032 m³/s/km².

10JA004 –Acasta River above Little Crapeau Lake – about 42 km north from the project site. The gauge has 14 complete years of daily flow data from 1980 to 1994. Its drainage area is 2,280 km² and its Mean Annual Flow (MAF) is 11.74 m³/s. The Unit Mean Annual Flow is 0.0051 m³/s/km².

7SA004 –Indin River above Chalco Lake – about 58 km east from the project site. The gauge has 31 complete years of daily flow data from 1977 to 2003. Its drainage area is 1,520 km² and its Mean Annual Flow (MAF) is 7.99 m³/s. The Unit Mean Annual Flow is 0.0053 m³/s/km².

The mean annual flow at the project site is determined based on data of WSC gauge 10JA004 which is the closest to proposed project. The Mean Annual Flow at the project site, based on a drainage area of 4,600 km², is 23.5 m³/s.

A frequency analysis of the peak instantaneous flows at WSC gauge 10JA004 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m³/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	256	248	520	500
1,000 year	324	312	655	630

The hydrology for the Emile River diversion project is discussed in the ‘Power Site Survey Northwest Territories’ 1979 report by UMA. The Mean Annual Flow at the site is estimated from the nearby WSC gauge 10JA002. The unit MAF of gauge 10JA002 is 0.0032 m³/s/km², which is less than that at gauge 10JA004. Note that at the time of the UMA report the WSC 10JA004 was not installed.

The 1979 UMA report states a spillway design flood of 3,160 m³/s at the site. Based on figure 4-6 of the UMA report, it seems that the spillway design flood is set equal to the 1,000-year peak daily flood (as estimated at the time of the 1979 report).

Based on 13 data points from 1981 to 1994, the peak daily flow at the WSC gauge ranges from 52 m³/s to 155 m³/s with an average value of 97 m³/s; while the peak instantaneous flow ranges from 52 m³/s to 157 m³/s with an average value of 98 m³/s.

4.1.3.7 Marion River Diversion

The nearest WSC gauges to the project site are

10JA002 -Camsell River at outlet of Clut Lake - about 203 km north from the project site. The gauge has 44 complete years of daily flow data from 1933 to 2008 (currently active). Its drainage area is 32,100 km² and its Mean Annual Flow (MAF) is 102.4 m³/s. The Unit Mean Annual Flow is 0.0032 m³/s/km².

7TB001 –Emile River at outlet of Basler Lake – about 49 km east from the project site. The gauge has 18 complete years of daily flow data from 1978 to 1997. Its drainage area is 4,850 km² and its Mean Annual Flow (MAF) is 15.49 m³/s. The Unit Mean Annual Flow is 0.0032 m³/s/km².

7SA003 –Snare River at Bigspruce Lake – about 60 km east from the project site. The gauge has 27 complete years of daily flow data from 1949 to 1976. Its drainage area is 15,200 km² and its Mean Annual Flow (MAF) is 48.7 m³/s. The Unit Mean Annual Flow is 0.0032 m³/s/km².

WSC gauge 7TB001 is used in the present analysis due to its proximity to the project. The Mean Annual Flow at the project site, based on a drainage area of 1,630 km², is 5.2 m³/s.

A frequency analysis of the peak instantaneous flows at WSC gauge 7TB001 is shown below (estimates at the project site are prorated based on drainage areas):

Peak Flows (m³/s)

Return Period	WSC – Instantaneous	WSC - daily	Site - Instantaneous	Site - Daily
200 year	77	77	26	26
1,000 year	89	89	30	30

The hydrology for the Marian River diversion project is discussed in the ‘Power Site Survey Northwest Territories’ 1979 report by UMA. The Mean Annual Flow at the site is estimated from the nearby WSC gauge 10JA002. The unit MAF of gauge 10JA002 is 0.0032 m³/s/km², which is similar to that at gauge 7TB001.

The 1979 UMA report also uses a spillway design flood of 1,890 m³/s at the site. Based on figure 4-6 of the UMA report, it seems that the spillway design flood is set equal to the 1,000-year peak daily flood (as estimated at the time of the 1979 report).

Based on 15 data points from 1979 to 1997, the peak daily flow at the WSC gauge ranges from 8 m³/s to 56 m³/s with an average value of 27 m³/s; while the peak instantaneous flow ranges from 8 m³/s to 57 m³/s with an average value of 30 m³/s.

4.2 Project layouts and Cost estimates

Based on the review of the outlined reports and studies and the 1:50,000 map of the project area only, and without benefit of site visits we think that the proposed hydroelectric sites and layouts of the identified schemes are mainly well conceived and appropriate for the given project locations and relevant topographical, hydrological, geological and other site conditions known at the time.

Sizes of the projects (installed capacity, capacity factor, design/rated flows) appear to be adequately selected based on the main project concepts and information available at the time.

Dam outlet works for the proposed dams are designed and sized according to regulations and codes applicable at the time:

- Spillways for the proposed earthfill dams are designed to 10,000 year floods
- Dam outlet works for concrete dams are sized to 1,000 year flood

In current dam engineering practice for large dams, as indicated previously, dam outlet works are sized to safely pass the Probable Maximum Flood (PMF). The current concept, if applied to the assessed schemes would result in higher costs of dam outlet works and associated hydromechanical and electrical equipment.

As presented in section 4.1 of this report the estimated hydrological input (mean annual flows, design and spillway floods) for the analyzed hydroelectric sites differs from the input estimated previously. This difference would have some impact on the project design, energy generation and associated cost of the schemes, but it is unlikely to change the rankings.

At this overview level of assessment of waterpower potential of the Sahtu Region and ranking of the identified hydroelectric opportunities we did not quantify a magnitude of such impact, and have assessed the schemes based on the main features and parameters determined in the outlined reports.

To assess and rank the identified projects and calculate a unit cost per MWh Sigma has briefly re-assessed the cost estimates provided at the time, and escalated them to 2009.

The re-assessment of the project costs was required to ensure that the initially estimated costs of each of the projects include all relevant costs excluding the cost of transmission lines and interest during construction.

The re-assessed costs have been escalated to 2009 price level by using annual construction cost indexes reported and published by US Bureau of Reclamation (2002) and Statistics Canada (2009). The USBR indices are exclusively related to construction of dams and hydropower schemes and the ones published by Statistics Canada relate to electric utility projects. An allowance for northern construction has been included.

Updated preliminary cost estimates for the identified medium head large-scale hydroelectric projects are given in table below:

	Hydroelectric Site	Installed Capacity (MW)	Annual Generation (GWh)	Estimated Cost ($ Mill)
1	Great Bear River - Wolverine Creek HPP	236	1,480	490
2	Great Bear River - Wolverine Creek HPP-A*	14	108	96
3	Great Bear River - St.Charles Rapids	126	780	286
4	Great Bear River - Lower Brackett	240	1,505	505
5	Great Bear River - Option A (sites 1, 3, 4)	602	3,765	1,281
6	Great Bear River - Head of Rapids	288	1,805	561
7	Great Bear River - Upper Brackett	280	1,755	575
8	Great Bear River - Option B (sites 6, 7)	568	3,560	1,136
9	Mackenzie River HPP	3,320	18,900	7,505
10	Carcajou River HPP	14	108	284
11	Mountain River HPP	14	108	190
12	Keele River HPP	14	108	200
13	Redstone River HPP	14	108	140
14	Camsell River HPP	25.50	173	390

The economic assessment of the projects is provided in Section 5 of the report.

4.3 Brief Assessment of Environmental Aspects and Impacts

This brief assessment is performed for the following identified hydroelectric sites:

1. Mackenzie River at Norman Wells
2. Great Bear River at Wolverine Creek
3. Great Bear River at St. Charles Rapids
4. Great Bear River at Lower Brackett
5. Great Bear River at Head of Rapids
6. Great Bear River at Upper Brackett
7. Carcajou River (Site C2)
8. Mountain River
9. Keele River
10. Redstone River
11. Camsell River at White Eagle Falls (without diversion)

Potential impacts to the biotic environment from development at these sites were assessed based on the determined design flow, dam dimensions (footprint), and extent of flooding upstream of the dam(s) being similar to those described in previous reports. For all sites, the impact of development was evaluated on a stand-alone Project basis; however, cumulative impacts from two or more Projects being constructed on the Great Bear River are also discussed.

Distribution and basic life history characteristics of fish species in the Northwest Territories (NT) were taken from Canadian Manuscript Report of Fisheries and Aquatic Sciences #2793 (Sawatsky et al. 2007). Maps of wildlife distributions as well as information on vegetation were obtained from the GNWT Department of Environment and Natural Resources. Additional sources of information are referenced as used in the text.

4.3.1 Fish and Fish Habitat

Construction of facilities for hydroelectric generation requires the permanent placement of instream structures, and by consequence, might result in the disruption or destruction of fish habitat. If fish are found within Project areas, a section 35 (Fisheries Act) authorization from Fisheries and Oceans Canada (DFO) will be required in order for the Project(s) to proceed. Additionally, the alteration of the annual flow regime (higher flows in dry months and lower flows in wet months) has the potential to impact fish species both positively and negatively. Higher flows in dry months (November through April) could provide additional wetted habitat for fish species downstream of the development. In contrast, decreased flows in typically wet months (May through October) have the potential to disrupt migratory signals for anadromous species and/or create new barriers to fish movement through difficult river sections, which ordinarily require high water for passage. These negative impacts could be mitigated by identifying specific critical migratory periods for fish species within the zone of influence of the Project and adapting flow releases accordingly.

4.3.1.1 Mackenzie River at Norman Wells

The Mackenzie River runs from Great Slave Lake near the Alberta border to the Beaufort Sea in the Arctic Ocean; spanning the Northwest Territories almost completely from north to south. The river is generally slow, wide and with an elevation difference of only approximately 150 m between Great Slave Lake and the Mackenzie Delta, comparatively low-gradient (Culp et al. 2005). These conditions along with the lack of major barriers to fish movement, allow for large-scale migration of fish in the Mackenzie River (Bodaly et al. 1989). A number of anadromous fish species such as arctic cisco, least cisco, lake whitefish, broad whitefish, and inconnu travel through and utilize various lengths of the river both as juveniles and as adults. Four species of Pacific salmon have also been observed in the Mackenzie River system; Chum, Coho, Sockeye and Chinook. The latter three species are regionally considered “Vagrant” as their usual range is not within the Northwest Territories, and individual populations are likely not self-sustaining. Conversely, Chum salmon have small, localized, but well established populations in upper areas of the Mackenzie River. Numerous freshwater fish species also inhabit the Mackenzie River system and travel extensive distances along the river during various life stages. A list of fish species with confirmed (observation in situ) or unconfirmed (observation in a connected waterbody) presence in the Mackenzie River is provided below. Further studies to confirm specific fish presence and migration through the Mackenzie River at the Norman Wells site will be necessary. In all likelihood, one requirement for a hydroelectric development at this site will be the incorporation of structure(s) that ensure safe fish passage (both adults and juveniles) around the dam.

Confirmed Presence		Unconfirmed Presence
Arctic lamprey	Round whitefish	Pearl dace
Goldeye	Mountain whitefish	Rainbow smelt
Lake chub	Chum salmon	Shortjaw cisco
Emerald shiner	Sockeye salmon	Coho salmon
Spottail shiner	Chinook salmon	Bull trout/Dolly varden
Northern redbelly dace	Lake trout	
Finescale dace	Inconnu	
Longnose dace	Arctic grayling	
Flathead chub	Trout-perch	
Longnose sucker	Burbot	
White sucker	Brook stickleback	
Northern pike	Ninespine stickleback	
Pond smelt	Slimy sculpin	
Cisco	Spoonhead sculpin	
Arctic cisco	Walleye	
Least cisco		
Lake whitefish		
Broad whitefish		

Many Mackenzie River fish species exhibit multiple life history types; predominantly a combination of anadromous, lacustrine, adfluvial, and/or riverine. Depending on the life history strategy of the specific populations near the Norman Wells site, the creation of a lake upstream of the dam may result in the loss or the creation of new fish habitat. Both the flathead chub and the longnose sucker predominantly exhibit either a riverine or adfluvial life history type, and if present in the Project area, would likely be negatively affected by the reduction of flows upstream of the dam. On the other hand, lacustrine-type species such as lake chub, emerald shiner, northern pike, cisco, and both species of dace may benefit from the new lake behind the dam.

4.3.1.2 Great Bear River

The Great Bear River flows between Great Bear Lake and the Mackenzie River. Like the Mackenzie River, the Great Bear River is a low-gradient waterway with no significant barriers to fish passage. As such, many of the fish species observed in the Mackenzie River utilize the Great Bear River as well. A summary of confirmed (observation in situ) and unconfirmed (observation in Great Bear Lake or Mackenzie River) fish species in the Great Bear River is provided in the list below.

Confirmed Presence		Unconfirmed Presence	
Lake chub	Round whitefish	Arctic lamprey	Arctic char
Emerald shiner	Mountain whitefish	Goldeye	Brook stickleback
Longnose dace	Chum salmon	Northern redbelly dace	Spoonhead sculpin
Flathead chub	Lake trout	Finescale dace	Deepwater sculpin
Longnose sucker	Inconnu	Pond smelt	
White sucker	Arctic grayling	Rainbow smelt	
Northern pike	Trout-perch	Shortjaw cisco	
Cisco	Burbot	Coho salmon	
Arctic cisco	Ninespine stickleback	Sockeye salmon	
Least cisco	Slimy sculpin	Chinook salmon	
Lake whitefish	Walleye	Pygmy whitefish	
Broad whitefish		Bull trout/Dolly varden	

Like in the Mackenzie River, many of the fish species known to occur in the Great Bear River are anadromous (inconnu, Arctic cisco) and/or predominantly riverine/adfluvial (Arctic grayling, mountain whitefish), and thus fish passage structures will likely be required as part of any and all development in this river.

The formation of a narrow lake in the river valley upstream of a Project at the St. Charles Rapids, Upper Brackett, Head of Rapids or Lower Brackett sites, may create new habitat for lacustrine species currently only known to be inhabiting Great Bear Lake including pond smelt, rainbow smelt, pygmy whitefish, Arctic char, lake trout, and deepwater sculpin. Equally, a new lake would reduce habitat for riverine and adfluvial fish populations who would likely move to faster flowing areas of the river either upstream or downstream of the Project's influence. If a cluster of Projects are constructed so that the entire length of the Great Bear River is replaced by a series of narrow lakes, all riverine habitat in the mainstem would essentially be lost. Fish populations with riverine or adfluvial life history strategies could no longer be supported by the river mainstem.

The development of a single Project or a full development of available waterpower potential at the Great Bear River is anticipated to result in little or no increase in lake level and will therefore likely have only minor effect on fish habitat in Great Bear Lake.

4.3.1.3 Tributaries to the Mackenzie River- Carcajou, Mountain, Keele and Redstone Rivers

The Carcajou, Mountain, Keele and Redstone Rivers are all direct tributaries to the Mackenzie River, and all of them lacking confirmed barriers to fish movement, and as a result all support similar fish populations. Unlike the Great Bear River, which is also a direct tributary to the Mackenzie River, these four rivers are not connected to a large lake and consequently, fewer lacustrine-specific fish species inhabit them. A summary of species presence (confirmed = C and unconfirmed = U) in each river is provided in the table below.

Table 1. Summary of confirmed (C) and unconfirmed (UC) fish presence in four tributaries to the Mackenzie River

Species	Carcajou River	Mountain River	Keele River	Redstone River
Arctic cisco	U	C	U	U
Arctic grayling	C	C	C	C
Arctic lamprey	U	U	U	U
Broad whitefish	C	U	U	C
Brook stickleback	U	U	U	U
Bull trout	C	C	C	C
Burbot	C	U	C	C
Chinook salmon	U	U	U	U
Chum salmon	U	C	U	U
Cisco	U	C	U	U
Emerald shiner	U	U	U	U
Finescale dace	U	U	U	U
Flathead chub	C	U	U	U
Goldeye	C	U	U	U
Inconnu	C	C	U	U
Lake chub	C	C	U	C
Lake trout	C	C	C	C
Lake whitefish	C	U	C	C
Least cisco	U	U	U	U
Longnose dace	U	U	U	U
Longnose sucker	C	C	U	C
Mountain whitefish	U	U	C	U
Ninespine stickleback	C	U	U	U
Northern pike	C	C	U	U
Northern redbelly dace	U	U	U	U
Pond smelt	U	U	-	-
Rainbow smelt	U	U	-	-
Round whitefish	U	U	U	C
Slimy sculpin	C	C	C	C
Sockeye salmon	U	U	U	U
Spoonhead sculpin	C	U	U	U
Spottail shiner	U	U	U	U
Trout-perch	C	C	U	U
Walleye	C	C	U	U
Yellow perch	-	-	U	U

Owing to a majority presence of migratory (adfluvial, anadromous) or riverine fish species in these four rivers, fish passage structures will likely form part of any development at the proposed Project sites.

Additionally, a stretch of riverine habitat will be lost to populations of these fish species through the formation of a storage lake. A small number of other species (lake chub, Northern pike and cisco) present in one or more of the four proposed rivers prefer slow moving water and may benefit from the creation of new habitat. Further studies will be required to verify site-specific species usage.

4.3.1.4 Camsell River at White Eagle Falls

Camsell River connects a series of small lakes located on the border between the Sahtu and North Slave Regions and ultimately spills into Great Bear Lake. Being further removed from the abundant fish species present in the Mackenzie River system, the Camsell River typically forms part of the upper limits to most species distributions. A list of fish species with confirmed and unconfirmed presence in the Camsell River is provided below.

Confirmed Presence	Unconfirmed Presence
Lake chub	Pond smelt
Longnose sucker	Broad whitefish
Northern pike	Chum salmon
Cisco	Arctic char
Lake whitefish	Inconnu
Round whitefish	Deepwater sculpin
Lake trout	Walleye
Arctic grayling	
Trout-perch	
Burbot	
Ninespine stickleback	
Slimy sculpin	

Those fish species with anadromous life history types (chum salmon, broad whitefish and inconnu) that are known to migrate as far as Great Bear Lake may inhabit and use the lower reaches of Camsell River as well. Several other species with riverine or adfluvial life history types also occupy Camsell River and therefore the requirement of fish passage structures around a dam at this site is probable.

The presence of multiple lakes upstream of the proposed Project development site will likely limit the extent of flooding. Consequently, limited new habitat would be created for lacustrine fish species; however, there will also likely be limited reduction of habitat for riverine or adfluvial species.

Protected Species

The shortjaw cisco has been given the status of “Threatened” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and is considered to be “At Risk” by the Northwest Territories General Status Ranking Program (NTGSRP). This species is specifically lacustrine and is known to occur in Great Bear Lake and Great Slave Lake; however, some degree of migration between the two lakes through the Mackenzie and Great Bear Rivers is possible. Two other species of conservation note are bull trout and inconnu, both of which are designated as “May be At Risk” by the NTGSRP. Further information regarding the use of waterways around the proposed Project sites by these species is required; however, the presence of shortjaw cisco in particular may complicate development at certain sites.

4.3.2 Wildlife and Vegetation

In comparison to areas with more temperate and southerly climates, the Sahtu Region of the Northwest Territories supports a restricted variety of plants and animals that are specifically adapted for the harsh northern climate. Because of their unique adaptations, however, some species reside solely in the Canadian arctic and their low population numbers have caused them to be recognized as protected species under federal (COSEWIC and the Species at Risk Act – SARA) and provincial legislation (Species at Risk (NWT) Act – anticipated to come into force in 2010). A summary of the protected species in the Sahtu region is presented in the table below.

Table 2. Summary of protected wildlife species in the Sahtu Region

Species	COSEWIC Status	*SARA* Status	NTGS Rank
Peregrine falcon *anatum-tundrius* complex	Special Concern	No status	Sensitive
Peregrine falcon subspecies *anatum*	Threatened	Threatened	Sensitive
Common nighthawk	Threatened	No status	Secure
Olive-sided fly catcher	Threatened	No status	Sensitive
Rusty blackbird	Special Concern	Special Concern	May be at Risk
Short-eared owl	Special Concern	No status	Sensitive
Eskimo curlew	Endangered	Endangered	At Risk
Horned grebe (Western population)	Special Concern	No status	Secure
Grizzly bear (Northwest population)	Special Concern	No status	Sensitive
Wolverine (Western population)	Special Concern	No status	Sensitive
Woodland caribou (Boreal population)	Threatened	Threatened	Sensitive
Woodland caribou (Northern Mountain population)	Special Concern	Special Concern	Secure

To date, no plant species have been ranked or assessed as being at some level of risk by either COSEWIC or SARA; however, 120 species of lichen, non-vascular and vascular plants have been given the rank of "May be at Risk" by the NTGSRP, which is used as a coarse filter for the Species at Risk (NWT) Act.

The ranges of all these species do not cover the entire Sahtu Region, and consequently, each proposed Project may impact wildlife and vegetation to a varying degree. Protected species with distributions known to overlap with proposed Project areas are summarized in the table below (Y = overlap, N = no overlap, F = fringe of distribution). Please note, the specific distributions of most plants in the Northwest Territories have yet to be mapped and detailed studies assessing presence/absence of species with conservation concern in Project areas will likely be required.

Table 3. Summary of protected wildlife whose known distributions overlap (Y), do not overlap (N) or are on the fringes (F) of certain proposed hydroelectric development sites

	Mackenzie River at Norman Wells	Great Bear River Projects	Carcajou River	Mountain River	Keele River	Redstone River	Camsell River at White Eagle Falls
Peregrine falcon *anatum-tundrius* complex and subspecies *anatum*	Y	Y	Y	Y	Y	F	Y
Common nighthawk	Y	Y	Y	Y	Y	Y	N
Olive-sided fly catcher	Y	F	Y	Y	Y	Y	N
Rusty blackbird	Y	Y	Y	Y	Y	Y	Y
Short-eared owl	Y	Y	Y	Y	Y	Y	Y
Eskimo curlew[1]	?	?	?	?	?	?	?
Horned grebe (Western population)	Y	F	Y	Y	Y	Y	N
Grizzly bear (Northwest population)	Y	Y	Y	Y	Y	Y	Y
Wolverine (Western population)	Y	Y	Y	Y	Y	Y	Y
Woodland caribou (Boreal population)	Y	Y	F	F	F	F	F
Woodland caribou (Northern Mountain population)	F	N	Y	Y	Y	Y	Y

[1]The population of Eskimo curlew is extremely low. The last unconfirmed sighting was in 1992. The current distribution is not known.

The two greatest impacts to terrestrial wildlife and vegetation from the development of a hydroelectric project at any site will be:

1. Disturbance during construction and
2. The loss of habitat by clearing and flooding.

Projects on Camsell River and Great Bear River at Wolverine Creek are expected to cause minimal flooding while the remaining nine Projects will result in the creation of new lakes of varying sizes. The greater the amount of land affected by clearing and flooding will likely directly determine the impact of a Project on wildlife and vegetation. However, these impacts are also dependent on the actual use or presence of wildlife and vegetation in potentially affected areas. Areas that will be cleared for such things as new roads and transmission line rights-of-way or flooded by the storage lake should be studied to determine habitat suitability for wildlife as well as presence of protected species.

Table 4. Preliminary ranking of potential hydroelectric development sites in the Sahtu region based on likely aquatic and terrestrial environmental impacts. Rated on a relative scale of 1 to 5 with 1 being the least impact of all Projects and 5 being the most impact of all Projects.

	Likely Fish Presence	Likely Terrestrial Protected Species Presence	Extent of Flooding
Mackenzie River at Norman Wells	5	5	3
Great Bear River Cluster			
Wolverine Creek	4	3	4
St. Charles Rapids	4	3	1
Lower Brackett	4	3	4
3 Project Scheme	4	3	5
Head of Rapids	4	3	4
Upper Brackett	4	3	4
2 Project Scheme	4	3	5
Carcajou River	3	4	4
Mountain River	3	4	3
Keele River	2	4	3
Redstone River	2	2	3
Camsell River at White Eagle Falls	1	1	1

4.4 Land Use Considerations for Hydropower Developments in the Sahtu Region

In order to assess any potential conflict between land use planning and conservation initiatives, and development of the region's hydro resources Sigma has briefly reviewed and evaluated the draft report: '*Land Use Considerations for Hydro Development in the Northwest Territories*' prepared by Stantec in June of 2009

The Stantec report outlines procedures and details of the land use planning process in the Northwest Territories including the area of the Sahtu Region. The report also provides some regulatory strategies regarding the planning of future hydroelectric developments and recommendations with respect to land use and hydropower developments.

Development and implementation of the Sahtu Land Use Plan (SLUP) is, according to the Stantec report, the responsibility of the Sahtu Land Use Planning Board (SLUPB). It is our understanding that the SLUP has not been approved yet and that the SLUPB has been conducting consultations on a draft SLUP. The SLUP zoning structure consists of:

- General Use Zones
- Special Management Zones
- Heritage Zones
- Conservation Zones

Any development within the outlined zones would be subject to the conditions that have been specified in the draft SLUP. Based on the Stantec report and input with respect to the SLUP, the assessed hydroelectric projects are located within the following land use zones:

Hydroelectric Sites	Land Use Zone
Great Bear River- Wolverine Creek HPP	Great Bear River Special Management Zone
Great Bear River- Wolverine Creek HPP-A*	Great Bear River Special Management Zone
Great Bear River-St.Charles Rapids	Great Bear River Special Management Zone
Great Bear River-Lower Brackett	Great Bear River Special Management Zone
Great Bear River-Head of Rapids	Great Bear River Special Management Zone
Great Bear River-Upper Brackett	Great Bear River Special Management Zone
Mackenzie River HPP	Special Management Zone
Carcajou River HPP	General Use Zone
Mountain River HPP	Conservation Zone
Keele River HPP	Conservation Zone
Redstone River HPP	Special Management Zone
Camsell River HPP	Special Management Zone

Please note that Figure 1 of our report depicting the identified hydroelectric sites in the Sahtu Region also shows the land use zones.

5 RANKING OF PROJECTS

The projects listed in section 4.2 are ranked by determining the unit cost per MWh for each scheme. In addition to the evaluation of the stand-alone projects listed in section 4.2, two additional schemes (options) related to full utilization of the available waterpower potential of the Great Bear River have been assessed (Developments consisting of two and three projects as outlined in Section 2.1 of the report).

The unit cost of power is estimated by dividing the annual estimated cost of the project by the average energy generated annually. The annual cost of the project reflects the levelized capital costs at an 8% real discount rate, assuming a 40 year project life and adding 2% of the original capital cost for annual maintenance and operating expenses. No interest-during-construction costs were included. Note that the unit cost is based on all of the energy being usable. Transmission costs are not included. Most of the assessed projects would be competitive with diesel generation.

The resulting cost of power ($/MWh) – shown in the table below - is a means of comparing different sites with a common parameter, and relating the cost to current rates payable for power. Once a project has been studied further, the actual unit cost of power must be determined by a more detailed financial analysis.

Ranking of potential sites

Assumptions

Financial Parameters	
principal	$1
interest	8%
term (years)	40
Annual unit cost	$0.0839
Maintenance	$0.0200
Total annual unit cost	$0.1039

	Hydroelectric site	Installed Capacity (MW)	Estimated Cost ($ Mill)	Annual Generation (GWh)	Unit Cost ($/MWh)	Ranking
1	Great Bear River - Wolverine Creek HPP	236	490	1,480	34.4	4
2	Great Bear River - Wolverine Creek HPP-A*	14	95.5	108	91.8	9
3	Great Bear River - St.Charles Rapids	126	286	780	38.1	7
4	Great Bear River - Lower Brackett	240	505	1,505	34.9	5
5	Great Bear River - Option A (Sites 1, 3, 4)	602	1,281	3,765	35.3	6
6	Great Bear River - Head of Rapids	288	561	1,805	32.3	1
7	Great Bear River - Upper Brackett	280	575	1,755	34.0	3
8	Great Bear River - Option B (Sites 6, 7)	568	1,136	3,560	33.1	2
9	Mackenzie River HPP	3,320	7,505	18,900	41.2	8
10	Carcajou River HPP	14	284	108	273.1	14
11	Mountain River HPP	14	190	108	182.7	11
12	Keele River HPP	14	200	108	192.3	12
13	Redstone River HPP	14	140	108	134.6	10
14	Camsell River HPP	25.5	390	173	234.1	13

6 SUMMARY AND RECOMMENDATIONS

The main objective of this study was to assess at an overview level the available waterpower potential in the Sahtu Region, and to identify hydroelectric sites that would be of interest to NWT. The hydropower potential of the region is a significant part of the total Northwest Territories hydropower potential, and has been a matter of interest and studies for a long time. The main hydropower resources in the Sahtu Region are the Mackenzie River and its larger tributaries.

Sigma has assessed 14 large scale hydroelectric projects that were identified in previous studies. Sigma also conducted a search for new hydroelectric sites focusing mainly on areas that were not considered or assessed in previous studies. The topographical and hydrological conditions of the screened and assessed areas are not favorable for hydropower developments in general, and we have not identified any new hydroelectric sites to recommend for further studies and analyses.

The assessment of the previously identified schemes included a brief evaluation of hydrological input, project layout, installed capacity, annual generation, and capital cost of the schemes. In addition, environmental aspects of the projects have been ascertained as well as issues with respect to potential conflict between the development of the projects and the land use planning and conservations initiatives in the region.

The main findings of our assessment can be briefly summarized as follows:

- The proposed hydropower sites and the layouts are well conceived and appear to be appropriate for the given project locations and relevant topographical, hydrological, geological and other site conditions as know at the time.
- The main project features such as installed capacity, capacity factor and design/ rated flow are adequately selected based on the main project concepts, and information available at the time.
- The hydrological estimates of the analyzed sites provided in this study (mean annual flows, design and spillway floods) differ from the hydrological input estimated in the previous reports and studies. This difference would have some impact on the project design, energy generation and associated cost of the schemes. To quantify this impact, more detail design considerations, which are outside of the scope of this study, are required. We would strongly recommend such studies to take place for some of the assessed sites at a time when other conditions favour their development.
- The identified projects are assessed and ranked based on the main parameters and features that their original designs call for (Installed Capacity and Annual Energy Generation). The capital costs of the projects are estimated based on the costs estimated in the original studies and designs. The initially determined costs are re-assessed, and escalated to 2009 price level by using annual construction cost indexes reported and published by US Bureau of Reclamation and Statistics Canada. An allowance for northern construction has been included.

- The ranking of the schemes is performed based upon the unit cost of energy $/ MWh, which is estimated by dividing the annual estimated cost of the project by the average energy generated annually. Note that the unit cost is based on all of the energy being usable, and it does not include the transmission costs.

The economic assessment performed (Section 5 of the report) indicates that the projects on the Great Bear River are the most financially attractive and viable. This is mainly due to its very favorable topographical and hydrological conditions, with the Great Bear Lake providing large storage capacity. The estimated unit cost of power for the projects along the Great Bear River varies from 32.3 $/MWh for the Head of Rapids HPP to 91.8 $/MWh for the 14 MW Wolverine Creek HPP.

As indicated in Section 2.1 of the report, two options for development of the available waterpower potential along the river were considered and assessed, each option consisting of 2 and 3 hydropower projects. The multi-stage development consisting of three schemes totaling 602 MW (Wolverine Creek, St Charles Rapids and Lower Bracket HPP) appears to be a better choice. It provides an additional 34 MW of capacity and greater flexibility with respect to development of the full available hydropower potential of the river. The St. Charles Rapids HPP due to its size appears to be the best suited for an initial development on the river. Our assessment of this particular project will be provided in phase 2 of the study.

The estimated unit cost of power for the Norman Wells HPP, the 3,320 MW large-scale run of river project on the Mackenzie River, is 41.2 $/MWh. It should be pointed out, that the development of this scheme with full supply level at an elevation of 90 m would result in flooding a long stretch of the Great Bear River, which precludes utilization of its full available hydro potential. This should be taken into account in the next phase of study and design of those schemes.

The unit cost of power for other identified schemes varies from 134.6 $/MWh for the Redstone River HPP to 273.1 $/MWh for the Carcajou River HPP, which is found to be the most expensive scheme. Unlike the Great Bear River and The Mackenzie River, the river basins that those schemes are proposed on, do not have such favorable hydrological and topographical conditions for hydropower developments. (The unit run off from the area is very low and the storage required to provide desirable firm energy is not available in the basins.)

- The analyzed hydroelectric sites are also assessed with respect to potential impacts to the biotic environment (fish and fish habitat, and wildlife and vegetation and flooding). Table 4 from Section 4.3 summarizes the findings of this brief assessment. The Camsell River HPP has the smallest environmental impact, while the Norman Wells HPP on the Mackenzie River has the biggest impact. Further studies are highly recommended for the most financially viable projects to assess in greater depth the project impacts and required mitigation measures.
- The potential conflict between the development of the projects and the land use planning and conservation initiatives in the Sahtu region is outlined in Section 4.2 of the report and Figure 1. Two of the assessed projects (the Mountain River and Keele River hydroelectric sites) are located in Conservation Zones.

The waterpower potential of the Great Bear River is definitely the most important and financially viable hydro resource in the Sahtu Region.

We think that further studies and design considerations are required to re-assess and optimize the ultimate concept of the 602 MW multi-stage hydropower development on the Great Baer River and the St. Charles Rapids HPP. We would suggest the optimization of the St. Charles Rapids HPP to take place after the concept of ultimate utilization of the Great Bear River waterpower potential is re-assessed and confirmed, especially with regard to the potential impact of the Norman Well HPP on the Mackenzie River.

The optimization of the development concept and project itself would need to be undertaken based on updated hydrological and topographical input, and more detail geological, hydrogeological and geotechnical assessments, site investigations, and environmental appraisal.

The project optimization, which will likely include the optimization of the project site, size and layout, would also need to be based on the current and anticipated energy load demands of both local and other energy market(s) of interest.

Transmission line configurations would be subject of separate studies and depend on the location and magnitude of electrical loads.

7 PRESENTATION OF THE STUDY AT SAHTU HYDRO SYMPOSIUM

The main findings of the study have been presented at the Sahtu Hydro Symposium that took place in Deline, Northwest Territories on February 16 and 17, 2010.

The symposium, which was hosted by the Deline Land Corporation and sponsored by NWT Energy Corporation (03), generated a big interest of the Sahtu regional organizations and residents of Deline. The following organizations were represented at the workshop:

- Sahtu Secretariat Incorporated
- Sahtu Dene Council
- Déline First Nation
- Déline Land Corporation (Host)
- Kasho Got'ine Charter Community
- Yamoga Land Corporation
- Fort Good Hope Metis Land Corporation
- Behdzi Ahda First Nation
- Ayoni Keh Land Corporation
- Tulita Dene Band
- Tulita Land and Financial Corporation
- Fort Norman Metis Land Corporation
- Norman Wells Land Corporation

Other attendees included representatives from the NWT Energy Corporation (03), Northwest Hydro Corporation, the Department of Industry, Tourism and Investment and Sigma Engineering.

The representatives of the Sahtu organizations and local communities provided a valuable input with respect to their energy needs and the main concerns on potential hydropower developments in the region. Their input and the study itself would constitute a base for further discussion and activities to be undertaken regarding utilization of available hydropower potential of the region.